THE CRITICAL GROWTH RATE FOR PARTICLE INCORPORATION DURING THE DIRECTIONAL SOLIDIFICATION OF SOLAR SILICON UNDER MICROGRAVITY

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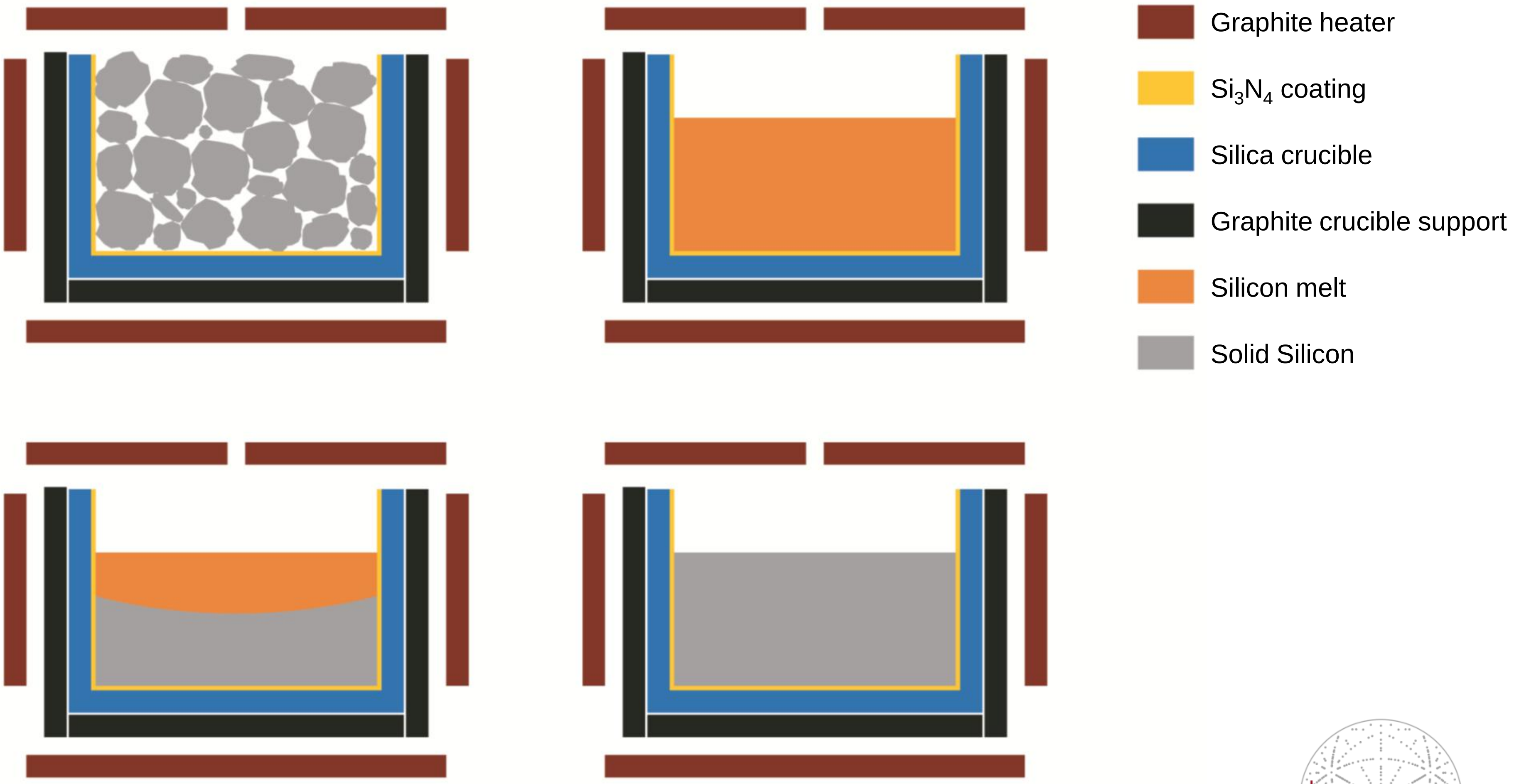
Outline

- Introduction
- Experiment - 1g
    - Results
- Experiment - µg
    - Results
- Outlook

Introduction



Introduction

Most important particle species in solar silicon:

SiC, Si_3N_4

Sources:

- Feedstock, graphite elements of the furnace, crucible material, crucible coating

Particles formed by precipitation when elements in the melt reach oversaturation

Introduction

Aim of the project:

Determine the critical growth rate in directional solidified solar silicon, to control the incorporation of foreign phase particles

- Reduction of unwanted particles in the bulk crystal volume to minimize shunts and wafer loss during wafering
- Defined incorporation of getter particles to improve the electrical properties of the wafer

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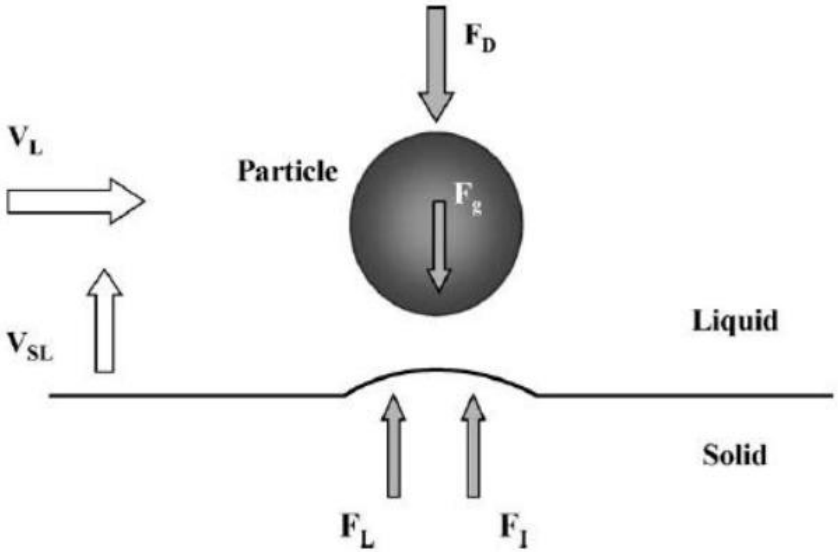
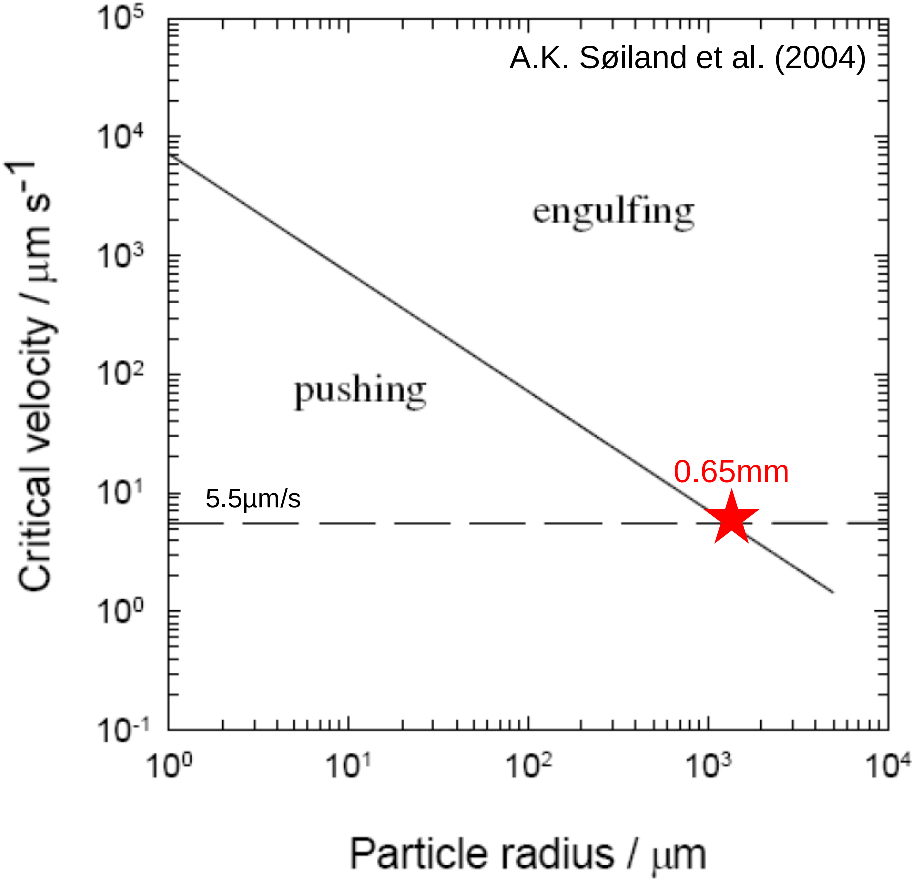
Introduction

Influencing forces on the particles:



After Y.M. Youssef et al. (2005)



<u>Forces on the particle:</u>

•Drag of the liquid melt

•Lift force due to convectional melt movement

•Interface force

•Gravity

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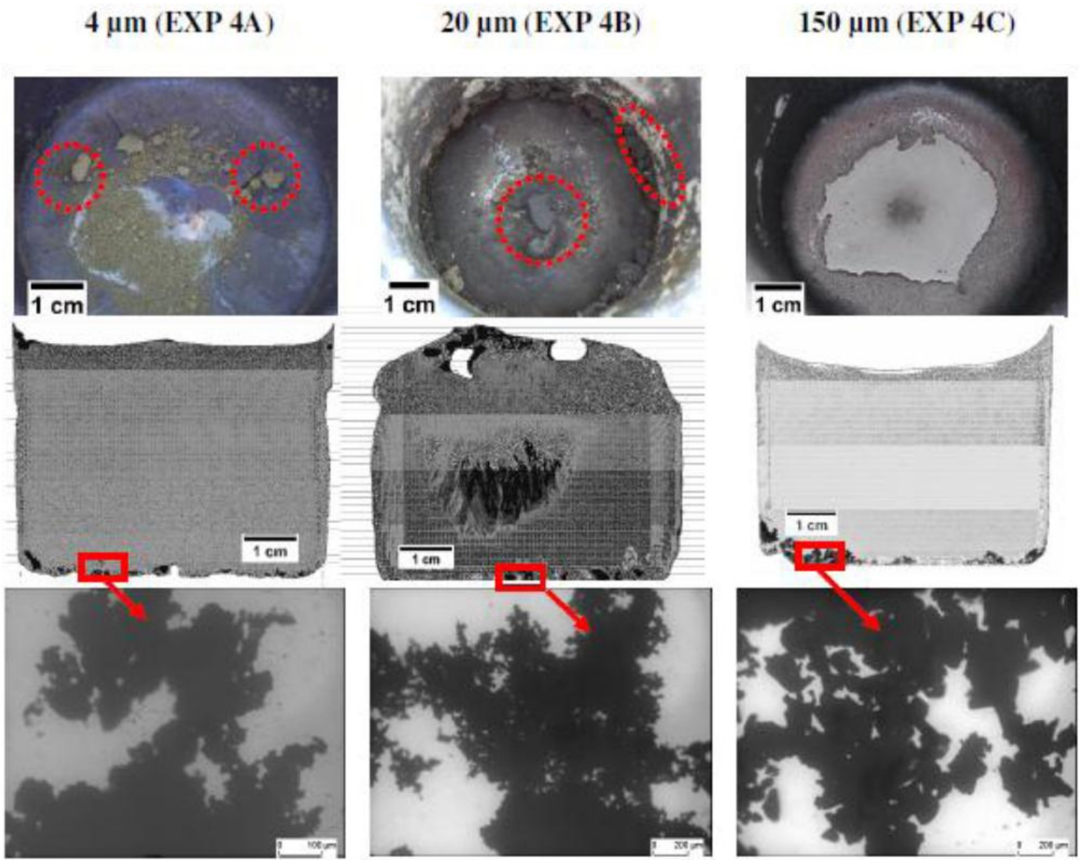
Introduction

Particle behaviour in silicon ingots for solar cells:



Experiments and images by Fraunhofer IISB

<u>4µm&20µm SiC particles:</u>

•Float to the top of the ingot

•Can agglomerate to large clusters

•Can stick to the bottom of the crucible

<u>20µm SiC particles:</u>

•Show precipitates in the centre of the ingot

Small particles are pushed by the solid/liquid interface

<u>150µm SiC particles:</u>

•Stay at the bottom of the ingot

No pushing, engulfment!

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Introduction

Why does the model deviate from the experiments?

Model was simplified:

- Interface roughness neglected
- Particles were assumed to be spherical
- Melt convection was not considered (no gravity!)
- Gravitational segregation (no gravity!)
- No chemical interactions in the melt assumed

Experimental conditions close to the existing models needed

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Experiment

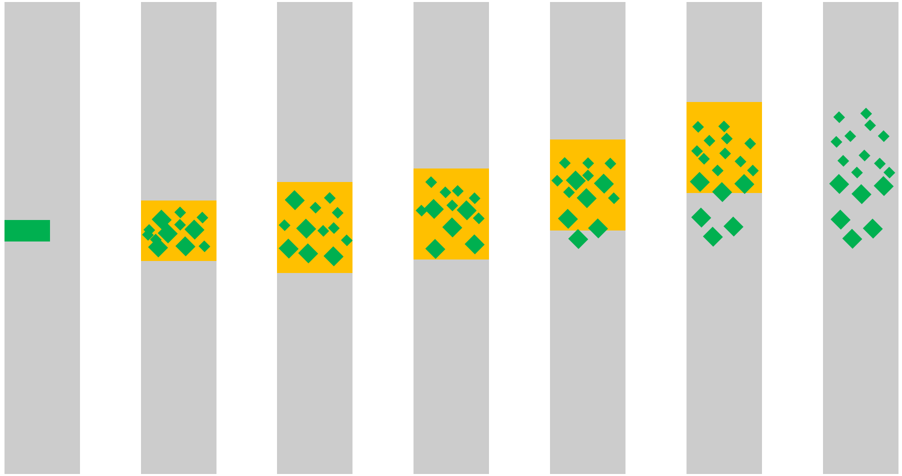
The experiment has to provide:

- Smooth solid/liquid interface
- Defined growth rates
- Diffusive or controlled convective conditions
- Defined/known particle size, shape, and chemistry
- NO GRAVITY

Experiment

TEM 02-3 ELLI module

- Mono ellipsoidal mirror furnace for floating zone growth of silicon
- Option for 7mT rotating magnetic field (50Hz)
- Oxide layer on sample surface suppresses Marangoni convection (diffusive conditions, shown on TEXUS 12)



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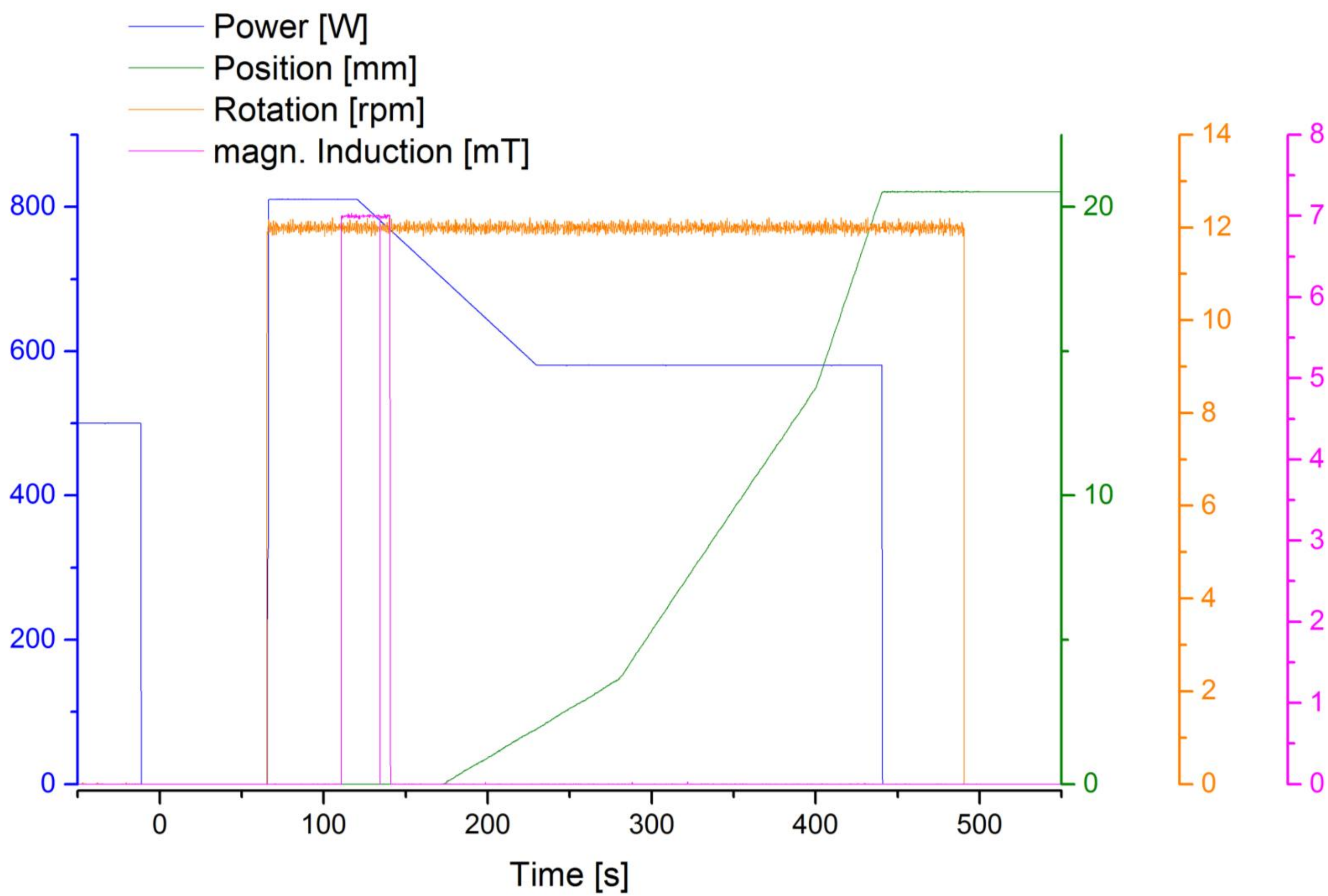
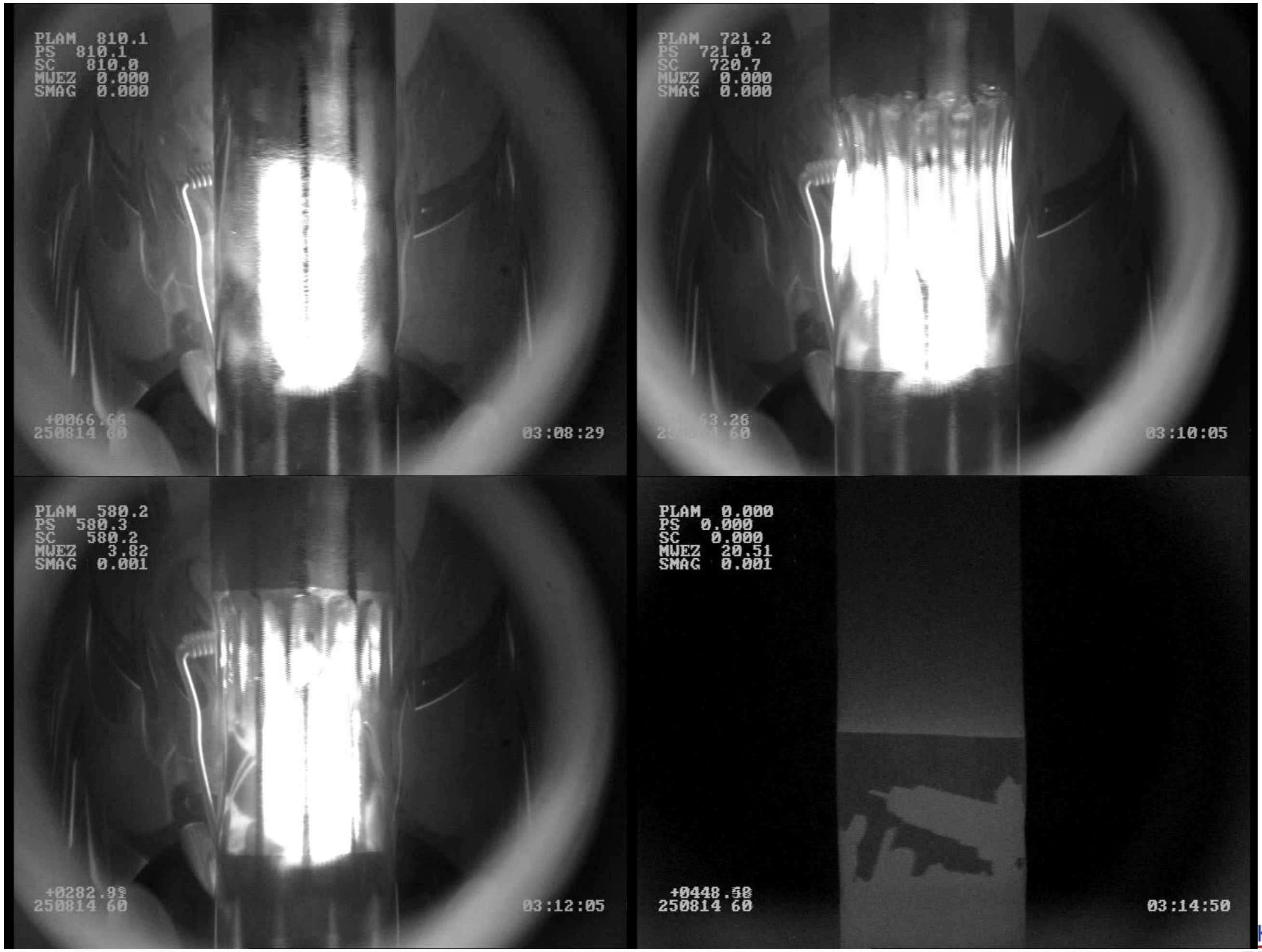
Experiment – 1g conditions



Results – 1g conditions

Floating zone growth of Si in the ELLI furnace:



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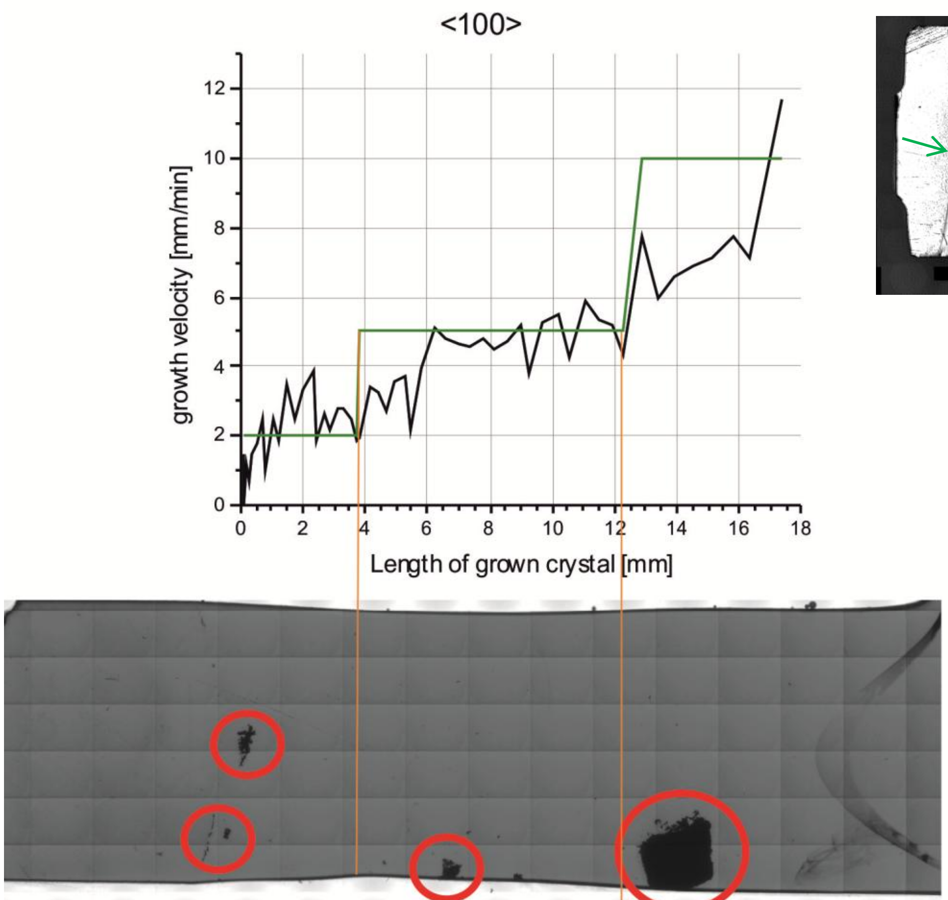
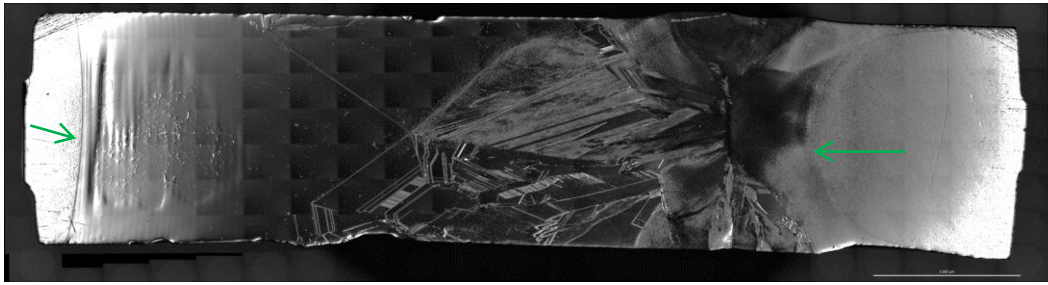
Results – 1g

Si [100] rod with 4mg of SiC particles (7&60µm size)



60µm 20-30µm 5-10µm



Using infrared and reflected light reveals:
- Size and location of particles
- Distinguishable clusters and individual particles
- Precipitates
- Twins → can serve as locator for particles
- Striations → show actual growth rate and phase boundaries

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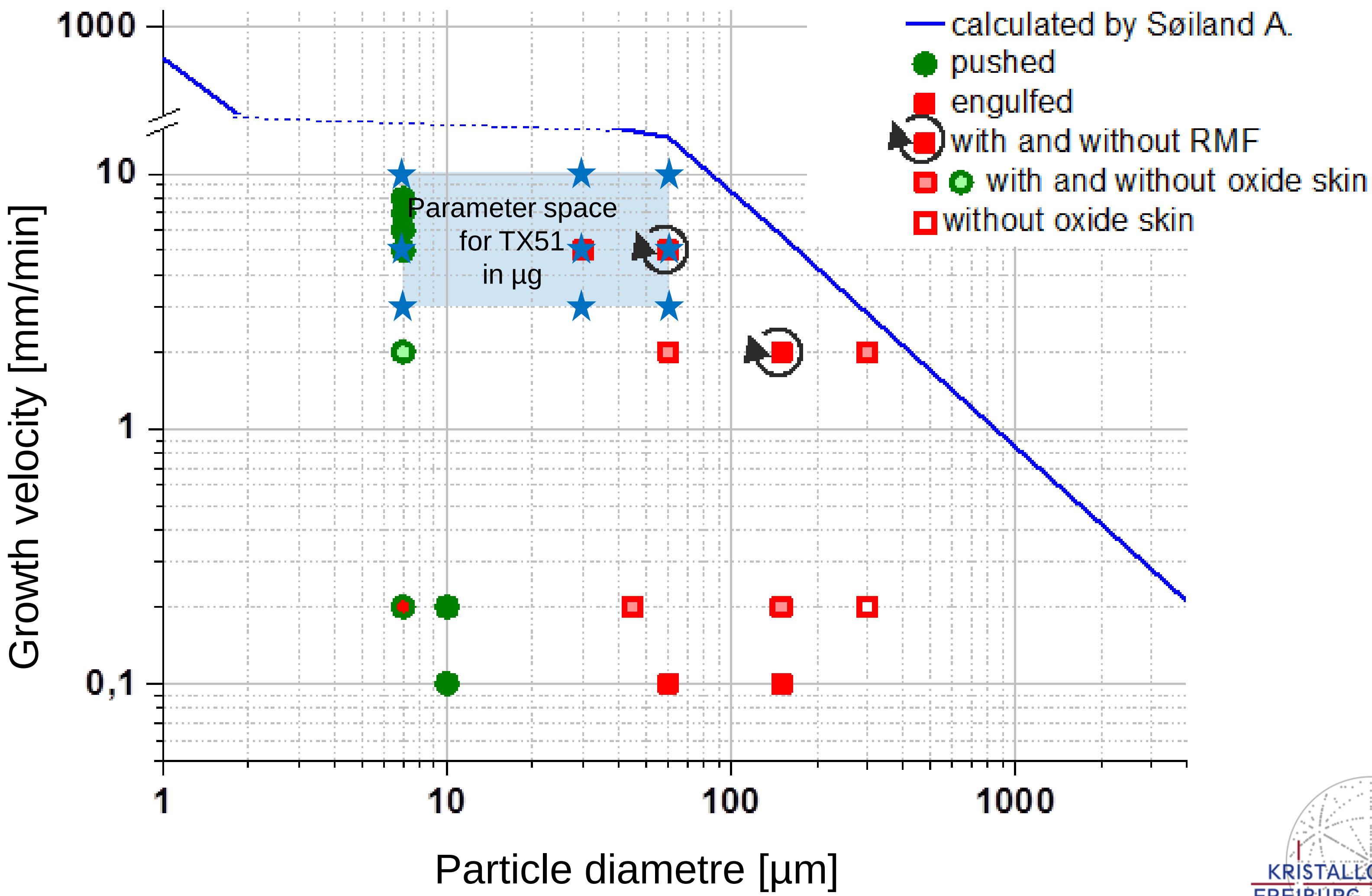
Results – 1g



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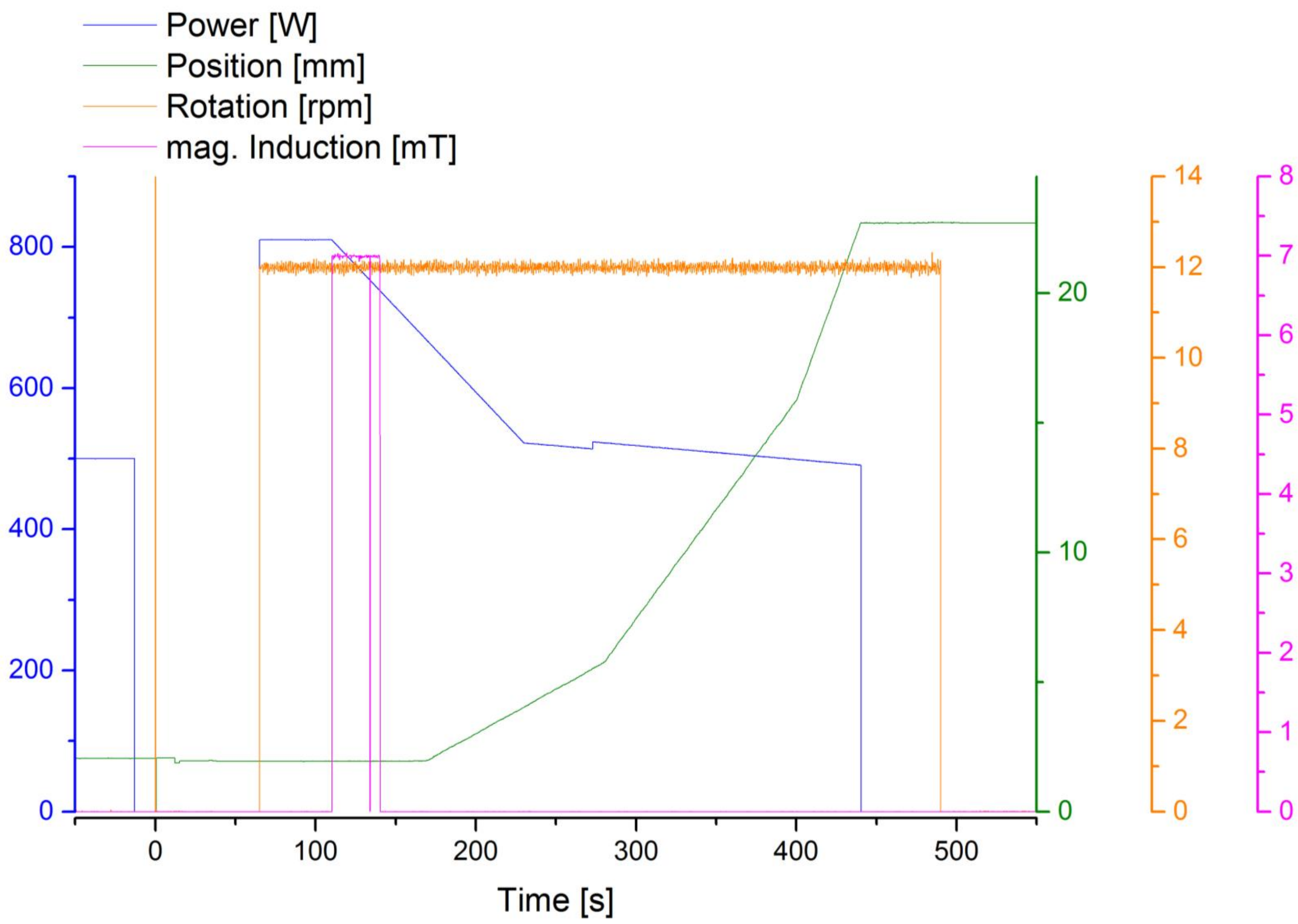
Experiment – µg conditions



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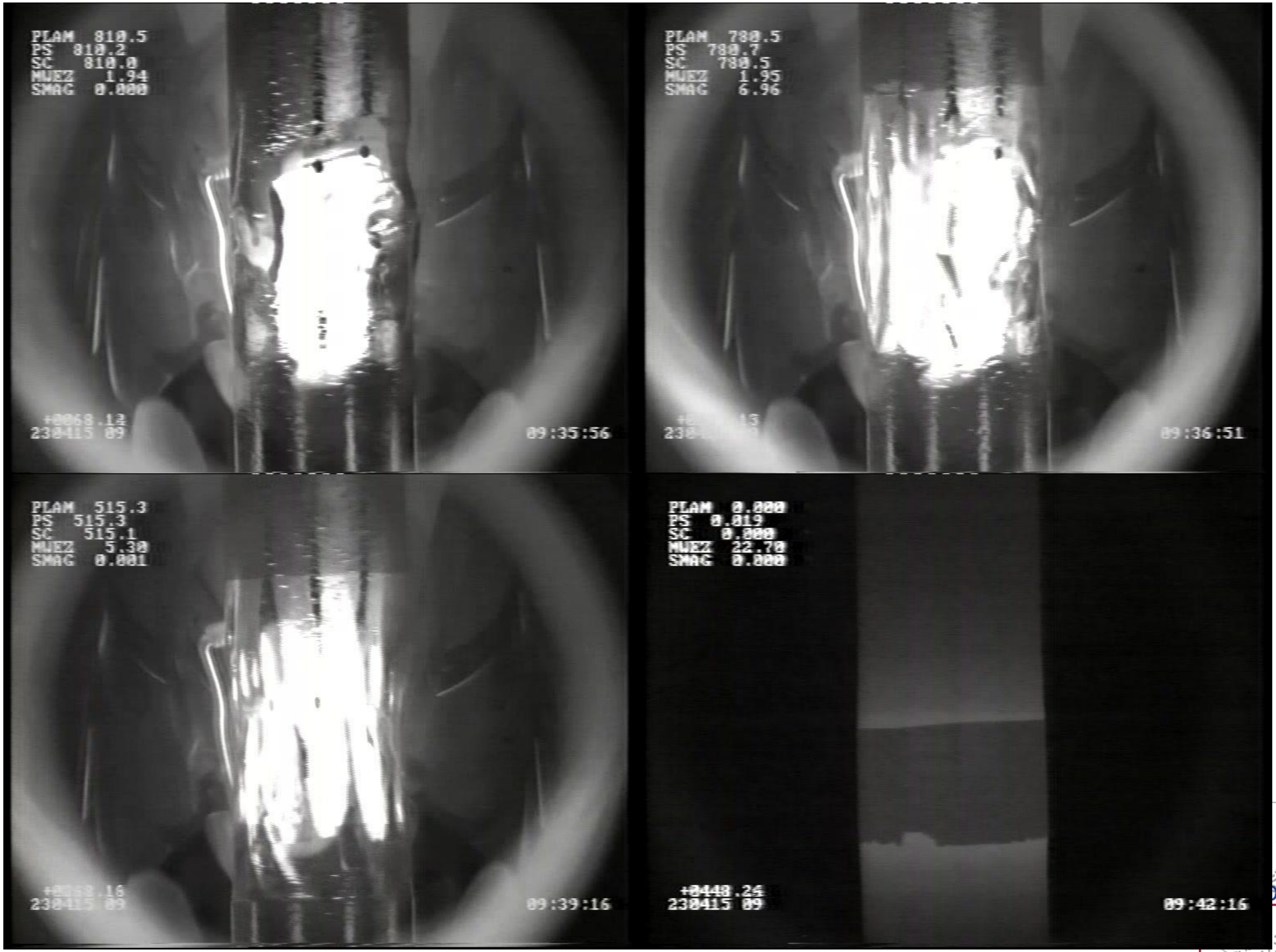
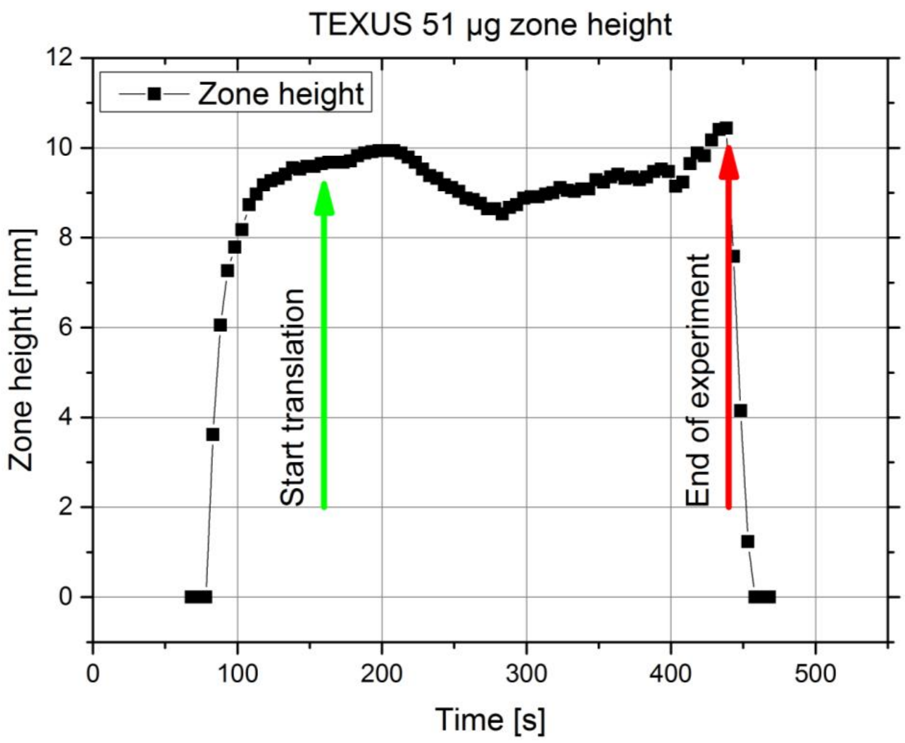
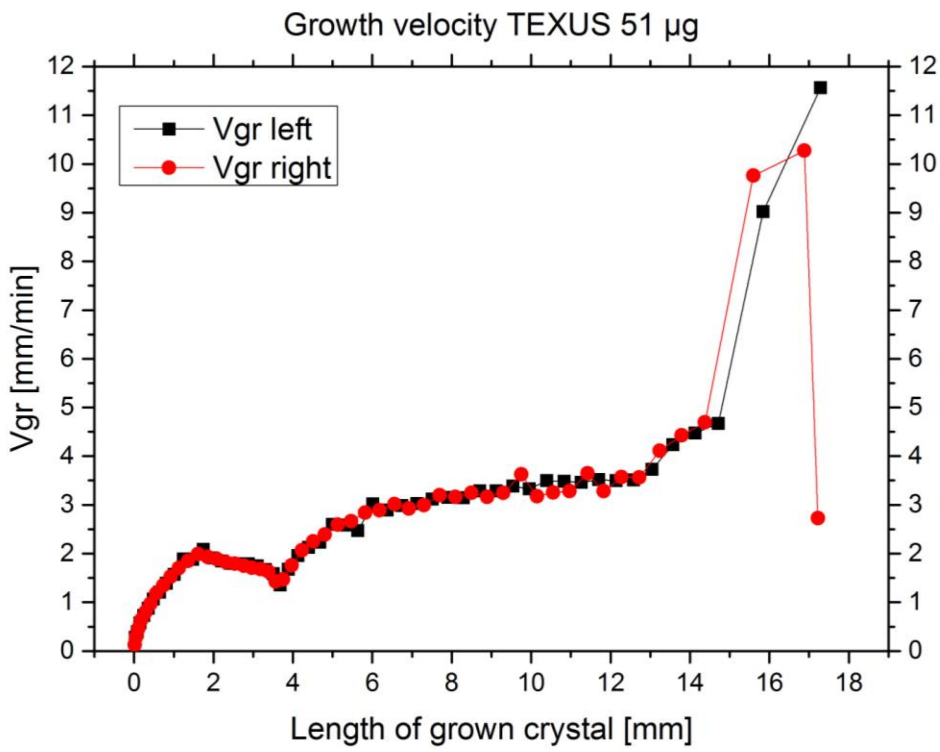
Results – µg conditions



Results µg conditions





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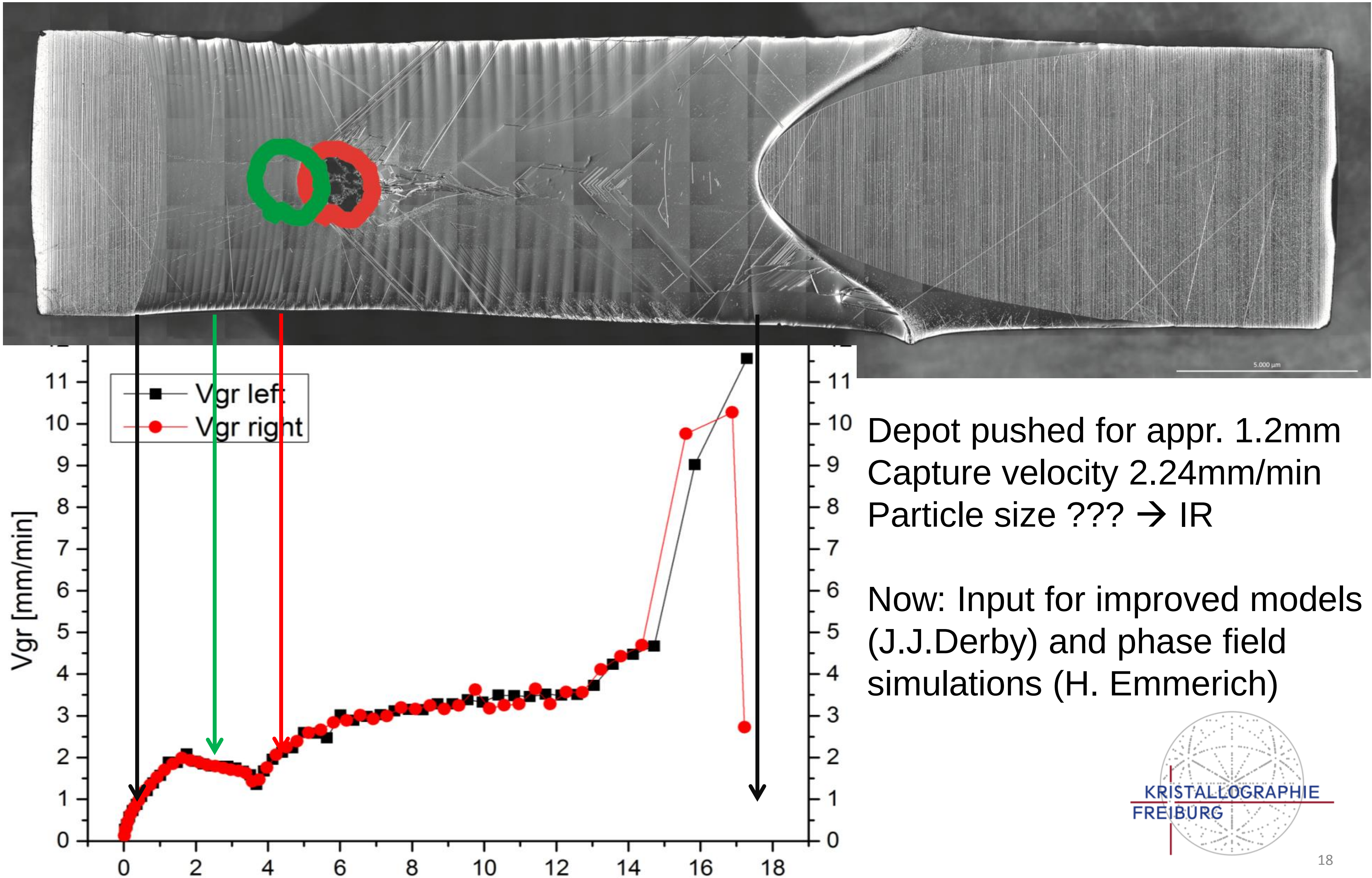
Results µg conditions



Depot pushed for appr. 1.2mm
Capture velocity 2.24mm/min
Particle size ??? → IR

Now: Input for improved models (J.J.Derby) and phase field simulations (H. Emmerich)

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Outlook

- Determination of particle sizes (defined data points for incorporation)
- Location of single particles (defined data points for incorporation)
- Input of capture velocities into models and phase field simulations
- Finish characterization of TEXUS 51 crystals

- Prepare for TEXUS 53
  - Different particle sizes/shapes/chemistry
  - Different crystal orientation (?)

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